3.G.12　c.　(cont'd)　required for the fusible element to begin to melt. An assumed "fuse damage," curve, approximated at 75% of the minimum melting curve, is used to provide a margin of safety so that applications avoid operation in the time-current band between the minimum melt curve and the total clearing curve, where current levels may cause thermal damage to the fuse without opening the circuit.

Current-limiting fuses are used to limit the magnitude and duration of extremely high fault currents during the total clearing time. Current limiting becomes effective only above a specific threshold current and interrupts the circuit in less than one-half cycle after occurrence of a fault, before the fault current reaches its maximum magnitude. Current-limiting fuses can be used in combination with circuit breakers to provide protection of the circuit breaker against high fault currents while retaining the time delay thermal and instantaneous magnetic trips for overcurrents of lower magnitude. The heat energy developed in a circuit during the fuse's clearing time, expressed in ampere-squared-seconds as I2t, is used as one measure of a fuse's current-limiting ability.

d.　Applications.　Overcurrent devices are generally required to be located at the point of supply of the circuit to be protected. The Electrical Engineering Regulations contain specific exceptions for overcurrent protection for generators, shore power cables, and transformer secondary circuits. Most conductors must be provided with overcurrent protection to protect against thermal damage caused by current in excess of the ampacity rating of the conductor.

This level of overcurrent protection is not desirable in circuits that would affect vessel operation if unexpectedly opened. Only short-circuit (not overload) protection, set not less than 500% of the expected current, is allowed in electric propulsion control, voltage regulator, and circuit breaker tripping control supply circuits. Exceptions are also made for applications such as motor circuits where a higher trip rating may be necessary to avoid tripping on motor inrush currents. Similarly, the overcurrent protection requirements for transformers contained in Article 450 of the National Electrical Code reflect the need to avoid improper tripping due to magnetizing inrush currents while providing adequate protection against sustained overcurrent. Due to the vital role of the steering system in the overall safety of a vessel, only limited fault-current protection is permitted in steering gear motor feeder, motor controller, control, and indicating and alarm circuits. It would be dangerous to "protect" a steering-gear motor against a moderate overload if, by tripping the motor during a maneuvering situation, steering were lost and the safety of the vessel jeopardized. The fault-current protection required for steering systems is intended to protect against fire; components of the system may be sacrificed in order to maintain control of the vessel for as long as possible in emergency situations. Steering gear and propulsion circuits must meet 46 CFR 111.70.

13.　Fault Current Analysis & Coordination (46 CFR 111.52).

a.　Purpose.　To provide for an electrical system that minimizes disruption from fault conditions, a fault current analysis and a coordination study must be performed. The fault current analysis is

3.G.13   a.   (cont'd)   used to determine the magnitude of available fault current throughout the system so that interrupting devices can be selected to safely open that magnitude of current. The coordination study is performed so that the overcurrent devices can be selected or set so that the device immediately upstream from the fault trips before devices further upstream, thereby limiting the power loss to equipment downstream of the fault.

Theory: The available short-circuit current at a given location in the power system is defined as the maximum current which the power system, when operating with the maximum generating capacity that can operate in parallel and the largest "probable" motor load, can deliver to a zero-impedance (bolted) three-phase fault. The sources of short-circuit current are the generators, synchronous motors or synchronous condensers, and induction motors in operation in the system. The connected (spinning) motors function as generators for a short time after a fault occurs, contributing current towards the fault. The subtransient reactance should be used to determine the contribution of induction motors to the fault current during the first few cycles after the occurrence of the fault.

The current that will flow toward the fault depends upon the power available from the source(s), the voltage at the fault (assumed to be zero for a bolted three-phase fault), and the impedance of the circuit components such as transformers, conductors, and other equipment between the fault and the power source(s). Short-circuit currents should be assumed to be asymmetrical during the first few cycles after the short occurs. The asymmetry will be maximum at the instant the short circuit occurs; in practical circuits containing both resistance and reactance, the current generally becomes symmetrical after several cycles. The rms value of the available asymmetrical current must be within the interrupting rating of the overcurrent device. Note that this maximum asymmetrical current is the average of the three phases at a particular instant in time and is not the maximum current in any one phase.

Low-voltage air circuit breakers operate nearly instantaneously for currents near their interrupting ratings. These breakers must be capable of interrupting the maximum current which can flow in the circuit However, since the interrupting ratings of low voltage circuit breakers are only expressed in terms of symmetrical rms amperes, only the symmetrical fault current needs to be determined. The breaker frame size should be selected to have a (symmetrical) interrupting rating at least equal to the calculated symmetrical short-circuit current.

Calculation Procedures: There are a number of methods, of various degrees of accuracy and simplicity, which can be used to determine the available fault current. The Electrical Engineering Regulations permit the use of the assumptions contained in 46 CFR 111.52-3 in lieu of detailed short-circuit calculations for systems with an aggregate generating capacity below 1500 kilowatts.

This refers to the condition where the maximum number of generators which can operate in parallel are operating, generating the maximum power which can be supplied to the system. Detailed calculations may utilize any of the following methods:

3.G.13.a   (1) Exact calculations using actual impedances and reactance's of the electrical equipment in the system.

(2) Estimated calculations using the Naval Sea Systems Command Design Data Sheet DDS 9620-3, "A.C. Fault Current Calculations."

(3) Estimated calculations using the International Electrotechnical Commission (IEC) Publication 363 (1972), "Short-circuit Current Evaluation with Special Regard to Rated Short-Circuit Capacity of Circuit Breakers in Installations in Ships."

(4) Estimated calculations using an established, commercially available fault current analysis procedure for utility or industrial applications, provided sufficient documentation regarding the procedure is submitted to verify its applicability. The estimated calculation procedure often contain certain "simplifying assumptions" regarding the reactance-to-resistance (X/R) ratios for generators, motors, and transformers, as well as the power factor and efficiency of induction motors. Low voltage systems are generally assumed to experience no voltage drop throughout the system. The maximum fault current is normally calculated at the first half-cycle. Simplifying assumptions may be used, consistent with good engineering judgment. The use of such assumptions must be noted in the calculations.

b.   Coordination. Coordination, sometimes called selectivity, refers to the location of overcurrent protective devices in the system and the selection of proper trip ratings or settings and coordination time intervals so that only the smallest practicable portion of the power system will be isolated following a fault. The protection system can be viewed as a set of overlapping zones of protection with each zone encompassing a segment of the power system including at least one circuit breaker or fuse, as shown in the figure below.

Protection System Zones

GENERATOR   TRANS.   LOAD

SWITCHBOARD

DISTRIBUTION PANEL
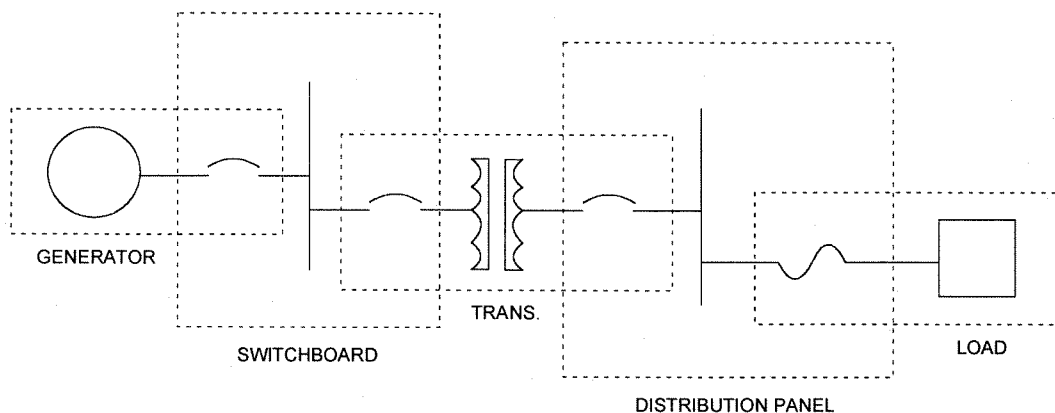
In a properly coordinated radial system, the first circuit interrupting device on the source side of the fault should respond (by opening the circuit) the fastest, so that no other interrupting devices open and maximum continuity of power is provided to the remainder of the system. Each circuit-interrupting device should